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High Altitude Platforms for Wireless Mobile Communication Applications

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1. Introduction

The wireless communications field has experienced an extraordinary development during the past two decades or so. New wireless technologies give people more convenience and freedom to connect to different communication networks. It is thought that the demand for the capacity increases significantly when the next generation of multimedia applications are combined with future wireless communication systems.

Wireless communication services are typically provided by terrestrial and satellite systems. The successful and rapid deployment of both wireless networks has illustrated the growing demand for broadband mobile communications. These networks are featured with high data rates, reconfigurable support, dynamic time and space coverage demand with considerable cost. Terrestrial links are widely used to provide services in areas with complex propagation conditions and in mobile applications. Satellite links are usually used to provide high speed connections where terrestrial links are not available. In parallel with these well established networks, a new alternative using aerial high altitude platforms (HAPs) has emerged and attracted international attentions (Mohammed et al., 2008).

Communications platforms situated at high altitudes can be dated to the last century. In 1960 a giant balloon was launched in USA. It reflected broadcasts from the Bell laboratories facility at Crawford Hill and bounced the signals to long distance telephone call users. This balloon can be regarded as an ancestor of HAPs. Traditional applications of airships have been restricted in entertainment purposes, meteorological usage, and environment surveillance due to safety reasons. However, in the past few years, technological advancements in communications from airships has given a promising future in this area (Karapantazis & Pavlidou, 2005).

HAPs are airships or planes, operating in the stratosphere, at altitudes of typically 17-22 km (around 75,000 ft) (Collela et al., 2000; Hult et al., 2008b; Mohammed et al., 2008; Yang & Mohammed, 2008b). At this altitude (which is well above commercial aircraft height), they can support payloads to deliver a range of services: principally communications and remote sensing. A HAP can provide the best features of both terrestrial masts (which may be subject to planning restrictions and/or related environmental/health constraints) and satellite systems (which are usually highly expensive) (Cost 297, 2005; Mohammed et al., 2008). This makes HAP a viable competitor/complement to conventional terrestrial infrastructures and satellite systems. Thus HAPs are regarded as a future candidate for next generation systems, either as a stand-alone system or integrated with other satellite or terrestrial systems.

HAPs as a new solution for delivering wireless broadband, have been recently proposed for the provision of fixed, mobile services and application as shown in Fig. 1 (Grace et al., 2001b; Yang & Mohammed, 2008a). HAPs can act as base-stations or relay nodes, which may be effectively regarded as a very tall antenna mast or a very Low-Earth-Orbit (LEO) satellite (Thornton et al., 2001). This modern communication solution has advantages of both terrestrial and satellite communications (Djuknic et al., 1997; Steele, 1992). It is a good technique for serving the increasing demand of Broadband Wireless Access (BWA) by using higher frequency allocations especially in mm-wavelength and high-speed data capacity. HAPs are also proposed to provide other communication services, i.e. the 3rd generation (3G) services. The International Telecommunication Union (ITU) gave licensed a frequency band around 2 GHz for IMT-2000 service (Grace et al., 2001a). An optical inter-platform link can be established between platforms to expand a network in the altitude to cover a large area. A broadband access link between the platform and user on the ground can be established to support different applications. Fixed, mobile and portable user terminals can be supported by the system. With assistance of terrestrial networks, HAPs can also provide the telecommunication services or the backbone for terrestrial networks in remote areas.

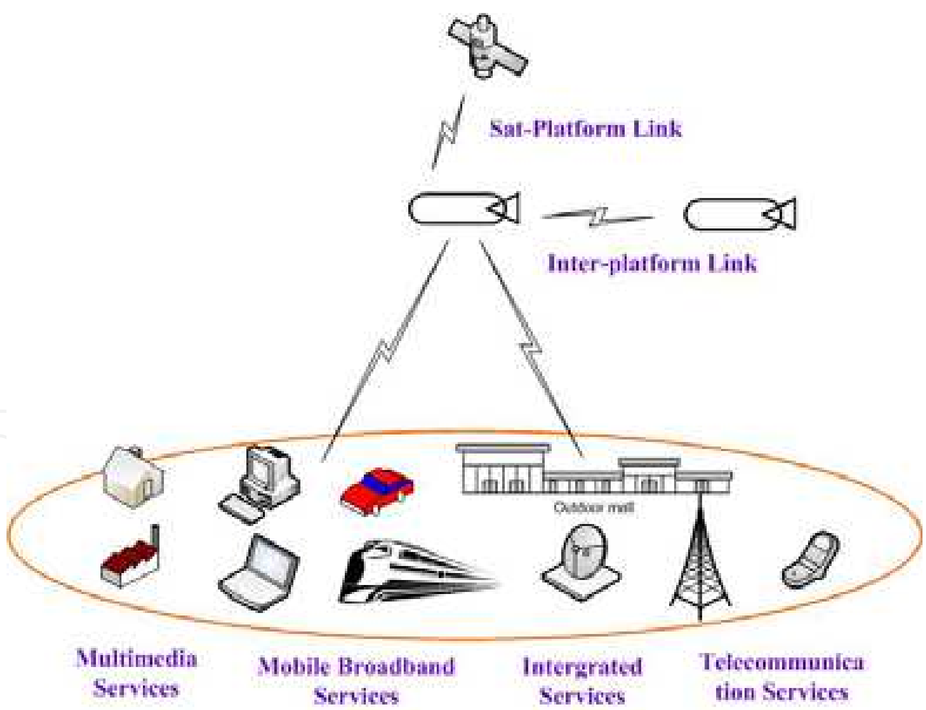

Fig. 1. HAP system deployed at 17~22 km above the ground

The full chapter is organized as follows: in section 1, we give an introduction to the HAP concept in wireless communications. In section 2, an overview of communication applications from HAPs, frequency allocations, well-known HAP research activities and trials are given. In section 3, main characteristics of HAP system are summarized and scenarios of HAP deployment are discussed. Finally, conclusions and future research are given in section 4.

2. Applications, Research and Trials of HAP Systems

2.1 Applications and frequency allocations of HAP System

HAPs have been proposed to deliver modern broadband services, i.e. high-speed internet, High-Definition Television (HDTV), Local Multi-Point Distribution (LMDS), Multi-Channel Multimedia Distribution Service (MMDS), and Wireless Interoperability for Microwave Access (WiMAX). All these services require wide bandwidth and high capacity. Generally these applications can be thought to equip base stations onboard, and based on well established terrestrial system design experience, but they are facing new challenges, e.g. cell structures, handover controls and dynamic channel assignment.

BWA services operate in the higher frequency bands, i.e. the mm-wave bands at several GHz, to provide the required radio frequency bandwidth allocation. The frequency bands allocated for LMDS in most countries in the world are around 30 GHz. ITU has assigned frequency bands of 47-48 GHz to HAPs worldwide. The 28-31 GHz bands have also assigned to HAP in some regions.

- On the ITU 1997 World Radio communication Conference (WRC-97), the ITU passed the RESOLUTION 122 to use the bands 47.2-47.5 GHz and 47.9-48.2 GHz for HAPs to provide the Fixed Service (FS) (ITU-R, 2003). WRC-2000 adopted the revision of RESOLUTION 122 to allow HAPs utilizing the bands 18-32 GHz, 27.5-28.35 GHz and 31-31.3 GHz in interested countries on non-interference and non-protection basis, which extended the previous RESOLUTION 122 (ITU-R, 2003). At the recent WRC-03 in ITU 2003, ITU gave the temporary RESOLUTION 145 [COM5/17] for potential using of the bands 27.5-28.35 GHz and HAPs in the FS (ITU-R, 2003).

HAPs may be one of the most important infrastructures for International Mobile Telecommunications (IMT-2000) 3G service, since HAPs can offer new means to provide IMT-2000 service with minimal network infrastructure. IMT-2000 standard has included provision for base-station deployment from HAPs and still needs further study before the deployment from HAPs in the areas of cell planning and antenna development. Employing access techniques such as Code Division Multiple Access (CDMA), Wideband-CDMA (W-CDMA) based IMT-2000 and CDMA based universal mobile telecommunications system (UMTS) from HAPs to provide 3G communications have been examined. (Foo et al., 2002; Hult et al., 2008a)

- RESOLUTION 221 was adopted by WRC-00 in ITU 2000 to approve HAPs providing IMT-2000 in the bands 1885-1980 MHz, 2010-2025 MHz and 2110-2170 MHz in with explicit region restrictions (ITU-R, 2003).

- RESOLUTION 734, which proposed HAPs to operate in the frequency range of 3-18 GHz, was adopted by WRC-2000 to allow these studies. It is noted that the range of 10.6 to 18 GHz range was not allocated to match the RESOLUTION 734.

2.2 HAP research and trails in the World

Many countries and organizations have made significant efforts in the research of HAPs system and its applications. Some well-known projects are listed below:

- The US Lockheed Martin compnay has won a contract from US Defense Advanced Research Projects Agency (DARPA) and the US Air Force (USAF) to build a high-altitude airship demonstrator featuring radar technology powerful enough to detect a car hidden under a canopy of trees from a distance of more than 300 km. Lockheed's Skunk Works division will build and fly a demonstrator aircraft with a scaled-down sensor system in fiscal year 2013 (Flightglobal, 2009).
- Since 2005 the EU Cost 297 action has been established in order to increase knowledge and understanding of the use of HAPs for delivery of communications and other services. It is now the largest gathering of research community with interest in HAPs and related technologies (Cost 297, 2005; Mohammed et al., 2008).
- CAPANINA of the European Union (EU) - The primary aim of CAPANINA is to provide technology that will deliver low-cost broadband communications services to small office and home users at data rates up to 120 Mbit/s. Users in rural areas will benefit from the unique wide-area, high-capacity coverage provided by HAPs. Trials of the technology are planned during the course of the project. Involving 13 global partners, this project is developing wireless and optical broadband technologies that will be used on HAPs (Grace et al., 2005).
- SkyNet project in Japan - A Japanese project lanuched at the beginning in 1998 to develop a HAP and studying equipments for delivery of broadband and 3G communications. This aim of the project was the development of the on-board communication equipment, wireless network protocols and platforms (Hong et al., 2005)
- European Space Agency (ESA) - has completed research of broadband delivery from HAPs. Within this study a complete system engineering process was performed for aerostatic stratospheric platforms. It has shown the overall system concept of a stratospheric platform and a possible way for its implementation (ESA, 2005).
- Lindstrand Balloons Ltd. (LBL) - The team in this company has been building lighter-than-air vehicles for almost 21 years. They have a series of balloon developments including Stratospheric Platforms, Sky Station, Ultra Long Distance Balloon (ULDB-NASA) (Lindstrand Balloons Ltd, 2005).
- HALE - The application of High-Altitude Long Endurance (HALE) platforms in emergency preparedness and disaster management and mitigation is led by the directorate of research and development in the office of critical infrastructure protection and emergency preparedness in Canada. The objective of this project has been to assess the potential application of HALE-based remote sensing technologies to disaster management and mitigation. HALE systems use advanced aircraft or balloon technologies to provide mobile, usually uninhabited, platforms operating at altitudes in excess of 50,000 feet (15,000 m) (OCIPEP, 2000).

- An US compnay Sanswire Technologies Inc. (Fort Lauderdale, USA) and Angel Technologies (St. Louis, USA) carried out a series of research and demonstrations for HAP practical applications. The flight took place at the Sanswire facility in Palmdale, California, on Nov. 15, 2005. These successful demonstrations represent mature steps in the evolution of Sanswire's overall high altitude airship program.
- Engineers from Japan have demonstrated that HAPs can be used to provide HDTV services and IMT-2000 WCDMA services successfully.

A few HAP trails have been carried out in the EU CAPANINA project to demonstrate its capabilities and applications (CAPANINA, 2004).

- In 2004, the first trial was in Pershore, UK. The trial consisted of a set of several tests based on a 300 m altitude tethered aerostat. Though the aerostat was not situated at the expected altitude it have many tasks of demonstrations and assessments, e.g. BFWA up to 120 Mbps to a fixed user using 28 GHz band, end-to-end network connectivity, high speed Internet, Video On Demand (VoD) service, using a similar platform-user architecture as that of a HAP.
- In October 2005, the second trial was conducted in Sweden. A 12,000 cubic meter balloon, flying at an altitude of around 24 km for nine hours, was launched. It conducted the RF and optical trials. Via Wi-Fi the radio equipment has supported date rates of 11 Mbps at distances ranging up to 60 km. This trial is a critical step to realize the ultimate term aim of CAPANINA to provide the 120 Mpbs data rate.

3. HAP Communication System and Deployment

3.1 Advantages of HAP system

HAPs are regarded to have several unique characteristics compared with terrestrial and satellite systems, and are ideal complement or alternative solutions when deploying next generation communication system requiring high capacity. Typical characteristics of these three systems are shown in Table 1.

Subject	HAPs	Terrestrial	Satellite
Cell radius	3~7 km	0.1~2 km	50 km for LEO
BS Coverage area radius	Typical 30 km ITU has suggested 150 km	5 km	A few hundred km for LEO
Elevation angles	High	Low	High
Propagation delay	Low	Low	Noticeable
Propagation Characteristic	Nearly Fress Space Path Loss (FSPL)	Well established, typically Non FPSL	FPSL with rain
BS power supply	Fuel (ideally solar)	Electricity	Solar
BS maintenance	Less complexity in terms of coverage area	Complex if multiple BSs needed to update	Impossible
BS cost	No specific number but supposed to be economical in terms of coverage area	Well established market, cost depending on the companies	5 billion for Iridium, Very expensive
Operational Cost	Medium (mainly airship maintenance)	Medium ~ High in terms of the number of BSs	High
Deployment complexity	Low (especially in remote and high density population area)	Medium (more complex to deploy in the city area)	High

Table 1. System characteristics of HAP, terrestrial and satellite systems.

The novel HAP has features of both terrestrial and satellite communications and has the advantages of both communication systems (Djuknic et al., 1997). The advantages include large coverage area, high system capacity, flexibility to respond to traffic demands etc. The main advantages can be summarized as following:

- Large-area coverage - HAPs are often considered to have a coverage radius of 30 km by virtue of their unique location (Djuknic et al., 1997; Grace et al., 2001b; Tozer & Grace, 2001). Thus, the coverage area is much larger than comparable terrestrial systems that are severely constrained by obstructions. HAPs can yield significant link budget advantage with large cells at the mm-wave bands where LOS links are required.
- Rapid deployment - A HAP can be quickly deployed in the sky within a matter of hours. It has clear advantages when it is used in disaster or emergency scenarios.
- Broadband capability - A HAP offers line of sight (LOS) propagation or better propagation non line of sight (NLOS) links owing to its unique position. A proportion of users can get a higher communication quality as low propagation delay and low ground-based infrastructure ensure low blocking from the HAP.
- Low cost - Although there is no direct evidence of HAP operation cost, it is believed that the cost of HAP is going to be considerably cheaper than that of a satellite (LEO or geostationary orbit (GEO)) because HAPs do not require expensive launch and maintenance. HAPs, can be brought down, repaired quickly and replaced readily for reconfiguration, and may stay in the sky for a long period. Due to the large coverage area from HAP, a HAP network should be also cheaper than a terrestrial network with a large number of terrestrial base stations.

3.2 HAP system deployment

Depending on different applications, HAP are generally proposed to have three communication scenarios with integration into terrestrial or satellite systems (Karapantazis & Pavlidou, 2005).

3.2.1 Terrestrial-HAP-Satellite system

The network architecture is shown in Fig. 2. It is composed of links between HAPs, satellite and terrestrial systems. It can provide fault tolerance, and thus support a high quality of service (QoS). Broadcasting and broadband services can be delivered from the platform. Inter-platform communications can be established for extending coverage area.

3.2.2 Terrestrial-HAP system

HAPs have been suggested by ITU to provide the 3G telecommunication services. HAP system is considered to be competitive in the cost compared to deploying a number of terrestrial base stations. In the architecture shown in Fig. 3, HAPs are considered to project one or more macro cells and serve a large number of high-mobility users with low data rates. Terrestrial systems can provide service with high data rates or in areas where NLOS propagation is mostly prevailing. The HAP network can be connected to terrestrial network through a gateway. Due to its wide coverage area and competitive cost of deployment, HAPs could be employed to provide services for areas with low population density, where it could expensively deploy fibre or terrestrial networks.

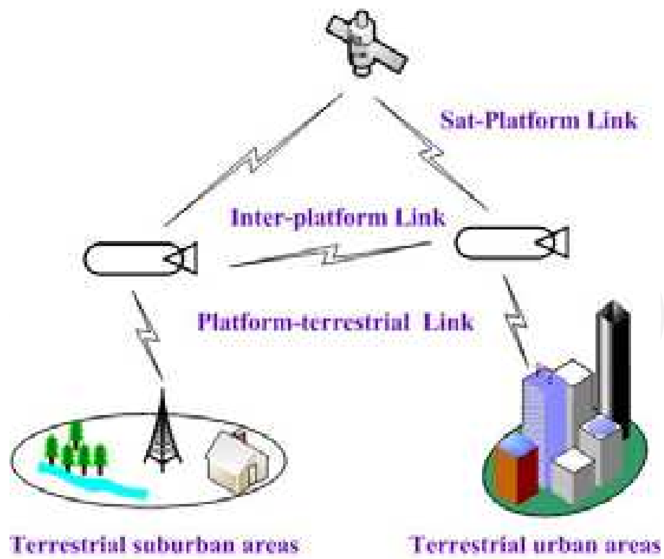

Fig. 2. Integrated Satellite-HAP-Terrestrial system

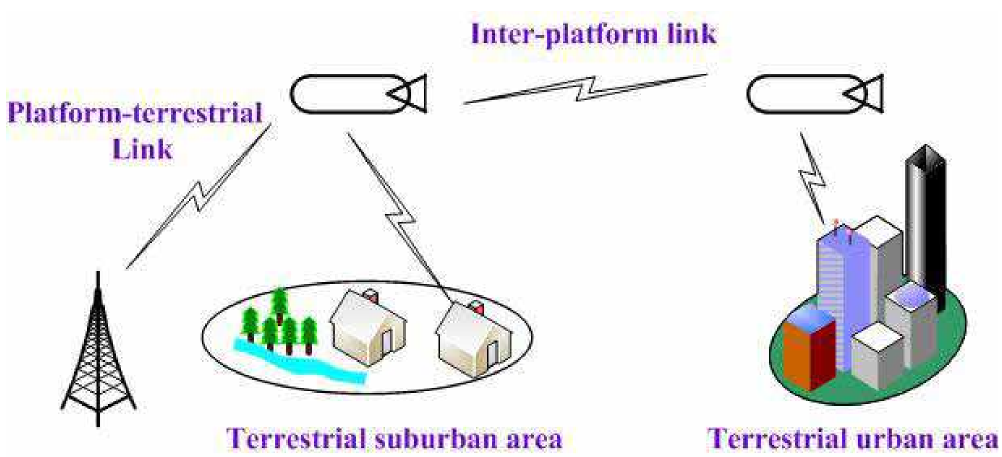

Fig. 3. HAP-Terrestrial system

3.2.3 A stand-alone HAP system

HAPs are potential to be a stand-alone system in many applications, e.g. broadband for all, environment and disaster surveillance. The architecture is shown in Fig. 4. In rural or remote areas, it is rather expensive and inefficient to deploy terrestrial systems. Furthermore, a satellite system is costly to be launched because of small traffic demand. HAPs system may be deployed economically and efficiently. A backbone link could be established by fibre network or satellites depending on applications.

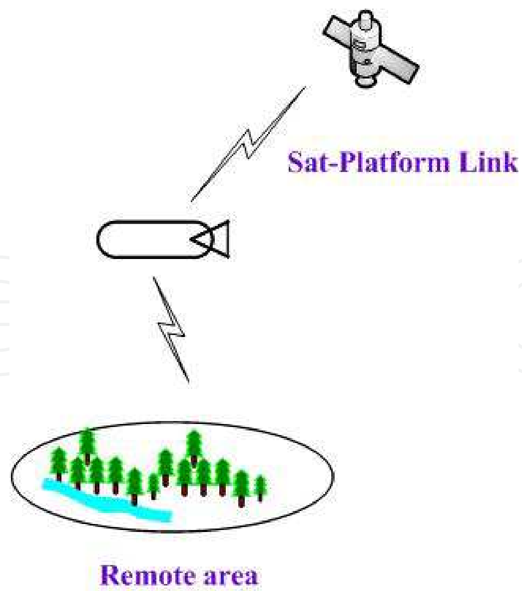

Fig. 4. A stand-alone HAP system

4. Conclusions and Future Research

In this chapter, an overview of the HAP concept development and HAP trails has been introduced to show the worldwide interest in this emerging novel technology. A comparison of the HAP system has been given based on the basic characteristics of HAP, terrestrial and satellite systems. Main advantages of HAPs for wireless communication applications in rural areas were wide coverage area, high capacity and cost-effective deployment. Three scenarios of HAP communication have been illustrated.

It is extremely beneficial to investigate other possibilities of providing mobile services from HAPs since this would provide an important supplemental HAP application under the goal "Broadband for All". Previous HAP application investigations in the CAPANINA project mainly addressed the fixed-wireless application in the mm-wave band at 30/31 GHz or even higher. Delivery of mobile services from HAPs enables HAPs to exploit the highly profitable mobile market. The IEEE802.16e standard and beyond provide both stationary and mobile services. To extend the HAP capabilities to support full operations under the WiMAX standards brings a more competitive service especially in the mobile service field. Some 3G HAP mobile communication studies have also been carried out in the 2 GHz band. High Speed Downlink Packet Access (HSDPA), which is usually regarded as an enhanced version of W-CDMA, and 3GPP Long Term Evolution (LTE) with MIMO and/or adaptive antenna systems capabilities for achieving higher data rates and improved system performance are also attractive directions for further investigations.

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Mobile and Wireless Communications have been one of the major revolutions of the late twentieth century. We are witnessing a very fast growth in these technologies where mobile and wireless communications have become so ubiquitous in our society and indispensable for our daily lives. The relentless demand for higher data rates with better quality of services to comply with state-of-the art applications has revolutionized the wireless communication field and led to the emergence of new technologies such as Bluetooth, WiFi, Wimax, Ultra wideband, OFDMA. Moreover, the market tendency confirms that this revolution is not ready to stop in the foreseen future. Mobile and wireless communications applications cover diverse areas including entertainment, industrialist, biomedical, medicine, safety and security, and others, which definitely are improving our daily life. Wireless communication network is a multidisciplinary field addressing different aspects raging from theoretical analysis, system architecture design, and hardware and software implementations. While different new applications are requiring higher data rates and better quality of service and prolonging the mobile battery life, new development and advanced research studies and systems and circuits designs are necessary to keep pace with the market requirements. This book covers the most advanced research and development topics in mobile and wireless communication networks. It is divided into two parts with a total of thirty-four stand-alone chapters covering various areas of wireless communications of special topics including: physical layer and network layer, access methods and scheduling, techniques and technologies, antenna and amplifier design, integrated circuit design, applications and systems. These chapters present advanced novel and cutting-edge results and development related to wireless communication offering the readers the opportunity to enrich their knowledge in specific topics as well as to explore the whole field of rapidly emerging mobile and wireless networks. We hope that this book will be useful for students, researchers and practitioners in their research studies.

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